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RESEARCH ARTICLE

# Does hemispheric lateralization influence therapeutic effects of transcranial direct current stimulation?

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## Abstract

This study investigated the effect of transcranial direct current stimulation (tDCS) polarity depending on lateralized function of task property in normal individuals performing visuomotor and simple repetitive tasks. Thirty healthy participants with no neurological disorders were recruited to participate in this study. Participants were randomly allocated into active or control condition. For the active condition, tDCS intensity was 2 mA with stimulation applied for 15 minutes to the right hemisphere (tDCS condition). For the sham control, electrodes were placed in the same position, but the stimulator was turned off after 30 seconds (sham condition). The tapping and tracking task tests were performed before and after for both conditions. Univariate analysis revealed significant difference only in the tracking task. For direct comparison of both tasks within each group, the tracking task had significantly higher Z score than the tapping task in the tDCS group ($P < 0.05$). Thus, our study indicates that stimulation of the right hemisphere using tDCS can effectively improve visuomotor (tracking) task over simple repetitive (tapping) task.

***Key Words:*** *nerve regeneration; transcranial direct current stimulation; visuomotor task; tracking task; task property; hemispheric lateralization; neural regeneration*

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## Introduction

The brain is divided into separate left and right hemispheres that are connected by the corpus callosum, a large network of fibers that communicates information between the hemispheres (Myers, 1959). However, each hemisphere has special features. Hemispheric specialization is a hemisphere-dependent relationship between a cognitive, sensory, or motor function and a set of brain structures (Herve et al., 2013). Generally, the left hemisphere is related to verbal and mathematical brain functions, particularly analytic, symbolic, computer-like, sequential logic processing. In contrast, the right hemisphere is spatial and mute, performing synthetic, spatio-perceptual, and mechanical information processing (Corballis, 1991). Such hemispheric specialization may also exist in the visuomotor control area. Rosenkranz et al. (2007) defined motor learning as the short-term acquisition of a visuomotor task, resulting in improved motor performance beyond pre-existing levels (Rosenkranz et al., 2007). Another study has demonstrated that the right hemisphere is superior to the left in terms of visuomotor control (Bracewell et al., 1990). A study on hemispheric specialization has shown that self-paced motor sequences such as finger-tapping test are closely related with the left hemisphere (Wittmann et al., 2001). It is known that motor performance or motor skill acquisition is improved by stimulation of the left hemisphere (Fregni et al., 2005; Reis and Fritsch, 2011). However, to the best of our knowledge, it is unknown that which hemisphere improves visuomotor coordination or simple repetitive tasks when the hemisphere is stimulated.

Transcranial direct current stimulation (tDCS) is a non-invasive, safe, and relatively painless method for modulating cortical activity. tDCS delivers a weak polarizing electric current to the cortex through a pair of electrodes, depending on the polarity of the current flow. Brain excitability can be either increased by anodal stimulation or decreased by cathodal stimulation (Holtzheimer et al., 2012). Generally, tDCS has been evaluated to modulate cognitive, linguistic, and motor performance in both healthy and neurologically-impaired individuals (Iyer et al., 2005). Regarding motor performance, the primary motor cortex (M1) is greatly involved in acquisition of motor skills in humans. Numerous studies using tDCS have demonstrated that anodal stimulation of the primary motor cortex results in increased performance (Nitsche et al., 2003; Lang et al., 2005; Kwon et al., 2008).

As previously mentioned, tDCS can promote or inhibit cortex activity depending on the polarity of current flow. If hemispheric lateralization related to motor performance can be modulated by the polarity of tDCS, then lateralized function of task property is likely to be an important issue for its application. To the best of our knowledge, there have been no reports investigating whether or not tDCS polarity depending on task property related to hemispheric lateralization can affect motor performance. Therefore, the aim of this study was to reveal the task property (visuomotor coordination or simple repetitive tasks) after stimulating the right hemisphere with anodal tDCS.

## Subjects and Methods

### Subjects

Thirty healthy participants (8 males, 22 females, with the age of 20–26 years) with no neurological disorder history were recruited from the Yeungnam College, Republic of Korea for this study and were confirmed to be right-handed by the modified Edinburg Handedness Inventory (mean score: 80.45 ± 17.52) (Caplan and Mendoza, 2011). All participants provided the written informed consent prior to the experiment. This study was approved by the institutional review boards of a university hospital and in accordance with the ethical guidelines of the *Declaration of Helsinki*. The subjects were interviewed about their state of health and were not taking any medication at the time of the experiment (**Figure 1**).

### Test procedure

This study was designed as a randomized double-blinded crossover trial. The participants and an experimenter (SMS) were blinded to this study. The preparatory and stimulation phases were applied at a constant current with an intensity of 1.0 mA for 2 minutes, with ramp up and down over the initial stage, and subjects were unaware of the stimulation conditions. Under the active condition, tDCS intensity was 2 mA while stimulation was applied for 15 minutes, in accordance with current safety data. Under the sham condition, the current was applied for 30 seconds at the beginning of the stimulation (Boggio et al., 2006). The tapping and tracking task tests were performed before and after tDCS motor phase.

A simple and constant current stimulator (Phoresor II Auto Model PM 850, IOMED®, Salt Lake City, UT, USA) was used to deliver a direct current of 2 mA for 15 minutes. The active electrode was a 7 cm × 5 cm oblong water-soaked sponge electrode. The 10/20 international electroencephalographic system, in which M1 corresponds to C3 or C4 in both hemispheres respectively, was used for electrode placement. This area is well known as the neural representational area of hand motor function (Jurcak et al., 2007).

The experimental apparatus for wrist-tapping task included a custom-made button (7 cm × 5 cm), a plastic-made frame for restriction of the metacarpal and carpal joints, and analog-to-digital data acquisition software using SuperLap Pro Ver 2.0 (Cedrus Corporation, San Pedro, CA, USA). Tapping of the button by the index finger was produced by flexion and extension of the wrist joint while the metacarpal and carpal joints were restricted by the plastic-made frame. All subjects performed three practice trials, each with a short duration of 5–7 seconds. All subjects were instructed to perform hand-tapping as fast as possible for 15 seconds. Three actual trials were recorded to allow direct comparison of differences.

The tracking task was produced by metaphalangeal joint extension and flexion movement. Participants were seated with their right elbows flexed on a table and used their left hands to hold a custom-made rotator machine with a built-in potentiometer. The task required the subject to track the target sine wave that was displayed as a red line on the computer screen for 15 seconds as accurately as possible. The response sine wave that was performed by each subject appeared as a black line, which drawn up as toward upper peak as the wrist was extended and *vice versa* (**Figure 2**). For the tracking task, accuracy of tracking performance (higher AI indicates higher accuracy) in each of the three trials was calculated as an accuracy index (AI = 100(P – E)/P), where E is calculated as the root mean square (RMS) error between the target and response lines, and P is the size of the individual's target pattern measured as the RMS value between the sine wave and vertical line at the upper and lower peaks. The magnitude of P is based on the scale of the vertical axis, which is each subject's range of wrist motion. Therefore, AI is normalized to each subject's own range of motion and takes into account any differences in excursion of the tracking target among subjects. The maximal score is 100. Negative scores occur when the response line is so distant from target that it falls on the opposite side of the midline.

### Statistical analysis

Demographic data, such as gender and age, were analyzed using an independent *t*-test. In order to compare the pre- and after-effects of the tDCS, repeated measures two-way analysis of variance was used. For direct comparison of differences between the tapping and tracking tasks within each group, data from the two motor tasks in both groups were converted into Z scores to standardize the performance of each motor task based on the mean and standard deviation of sham-controlled subjects (Z score = (post-task – mean of pre-task)/standard deviation of pre-task). Statistical analysis was performed using PAWS 18.0 (SPSS, Chicago, IL, USA). The level of statistical significance was chosen as 0.05.

## Results

### Number analysis and general data of participants

Three participants were excluded in this study because they had adverse effects such as headache and nausea during this study. The mean age of the tDCS group (four men and nine women) was 22.00 ± 0.82 years and that of the sham tDCS group (four men and 10 women) was 21.07 ± 0.99 years. There were no significant differences in age and gender between the tDCS and sham tDCS groups.

### tDCS stimulated good performance in the tracking task

**Tables 1** and **2** indicate the mean and standard deviation of the AI, inter-tap interval, and Z score for each group. Two-way analysis of variance with factor time showed significant difference between the two groups ($P < 0.05$). In addition, two-way analysis of variance with factor group by time showed significant interaction ($P < 0.05$). This result suggests that AI increased under tDCS condition as compared to sham tDCS condition. For direct comparison of both tasks within each group, Z score of tracking task was significantly higher than that of tapping task in the tDCS group ($P < 0.05$) (**Table 2**). The results indicate that the tDCS group showed better performance in the tracking task.

**Table 1 The mean and SD of AI and the SD of inter-tap interval under tDCS and sham conditions**

| | tDCS condition | | Sham condition | | | | |
|---|---|---|---|---|---|---|---|
| | Pre-task | Post-task | Pre-task | Post-task | Test | Condition | Interaction (Test × condition) |
| AI | 7.68±1.49 | 8.65±0.71 | 8.14±0.63 | 8.41±0.89 | 0.00 | 0.76 | 0.03 |
| SD of inter-tap interval | 22.10±5.58 | 21.42±5.14 | 24.72±10.83 | 25.25±11.41 | 0.95 | 0.32 | 0.61 |

AI is calculated for evaluation of the accuracy of tracking performance in each of three trials. Lower SD of inter-tap interval means more regular interval. Data are expressed as the mean ± SD and were analyzed using repeated measures two-way analysis of variance.

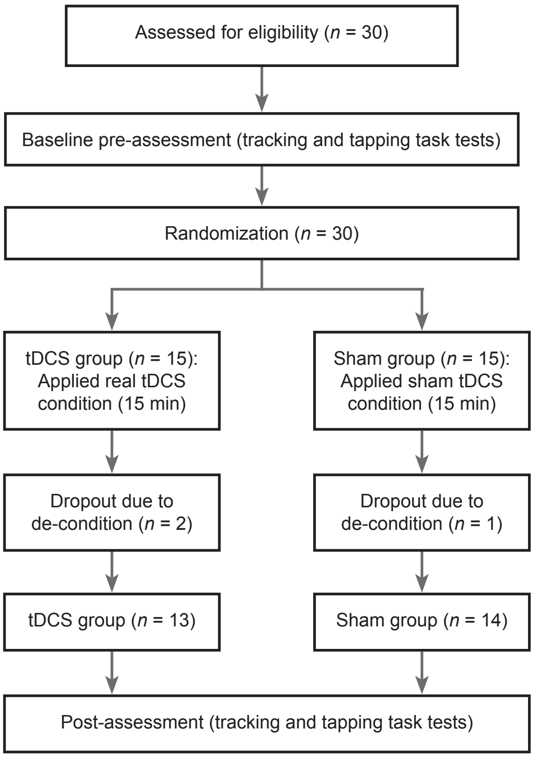


**Figure 1 Flow chart of experimental procedure.**
tDCS: Transcranical direct current stimulation; min: minutes.

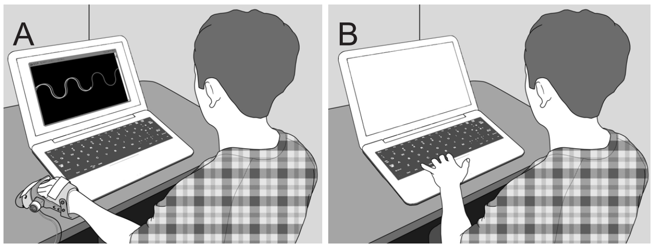


**Figure 2 Depiction of protocol of each task.**
(A) Visuomotor coordination task (tracking task). (B) Simple repetitive task (tapping task).

**Table 2 The mean and standard deviation (SD) of Z score in each group**

| | tDCS condition | Sham condition |
|---|---|---|
| Z score (tracking) | 0.69±0.51 | 0.31±1.35 |
| Z score (tapping) | 0.11±0.81 | –0.08±0.96 |
| *P* | 0.04* | 0.39 |

Data are expressed as the mean ± SD and were analyzed using independent $t$-test.*$P$ < 0.05; tDCS: Transcranical direct current stimulation; min: minutes.

## Discussion

This study investigated the effect of tDCS polarity depending on hemispheric lateralized function of task property in normal individuals performing visuomotor and simple repetitive tasks. The study detected hemispheric lateralization of the right hemisphere through comparison of motor performance between tracking (visuomotor task) and tapping (simple repetitive task) tasks. For objective comparison, each pre-after task variation was compared using a Z score. Our results demonstrated that tracking task was more effective in the right hemisphere than tapping task.

Finger-tapping tasks are simple repetitive tasks that are commonly used to study the human motor system. Tapping tasks have the advantage of being simple enough to use in both normal control subjects as well as those with neuropathologies affecting the motor system (Witt et al., 2008). In addition, finger-tapping tasks are relatively unaffected by cognitive and perceptual demands or cultural experience (Collyer et al., 1994). In the tapping task of this study, we used standard deviation of the inter-tap interval to evaluate the degree of uniformity of the temporal variable. The results did not find any significant effect of time or group-by-time interaction. Roy et al. (1992) previously reported that neither left nor right hemisphere-damaged patients exhibit an impaired tapping rate. However, impairment in tapping variability was observed but only in the left hemisphere group. That study partly supported our results. It was also proposed that inter-tap variability may be particularly sensitive to left hemisphere damage, which often leads to compromised agonist-antagonist muscle activations in tapping (Roy et al., 1992). According to several studies, patients with injuries to their left hemisphere commonly exhibit deficits in copying hand movements and control of repetitive motor behavior (Kimura and Archibald, 1974; Harrington and Haaland, 1991; Hermsdorfer et al., 1996). These findings suggest that right hemispheric lateralization is not strongly related to simple repetitive tasks such as finger-tapping.

Finger-tapping task is relatively unaffected by cognitive and perceptual demands, whereas tracking task has been recognized as a skilled complex motor action that requires eye-hand coordination (Carey et al., 2002; Brown et al., 2004). In this study, AI served as an indicator of tracking performance accuracy. Our results show that AI increased under tDCS condition compared to sham tDCS condition. Tracking task had significantly higher Z-score than tapping task in the tDCS group. These results indicate that the tDCS group performed better in the tracking task. The right hemisphere is thought to be involved in the global processing required for visuospatial analysis (Biermann-Ruben et al., 2008), such as mapping target and limb positions, as well as in visual processing prior to movement, which is independent of a case that whether the target location is known or unknown in advance (Fisk and Goodale, 1988; Hodges et al., 1997).

According to Farne et al. (2003), the right hemisphere contributes to processing of visuomotor information as well as executing actions with the ipsilateral hand in the contralateral space (Farne et al., 2003). Another study has suggested that the right hemisphere plays a special role in handgrip formation and rapid on-line visuomotor transformations (Hermsdorfer et al., 1999). Further, Bracewell et al. (1990) suggested that the right hemisphere is superior to the left in terms of oculomotor control. Many studies have supported a link between the right hemisphere and visuomotor process.

To improve motor performance, tDCS can be used. However, there exists hemiplegic lateralization according to right or left hemisphere, as each has specific functions. In the present study, we demonstrated that stimulation of the right hemisphere through tDCS improved visuomotor task performance over a simple repetitive task. Therefore, our study indicates that defining the dominant hemisphere according to task property followed by stimulation through tDCS is efficient for motor improvement. Our study has some limitations including small sample size and confined age range of the subjects. Further, we only tested the right hemisphere. Thus, future studies will be required to investigate the dominant function of the left hemisphere in terms of motor performance according to task property.

**Author contributions:** *YHK designed and supervised the study. SMS performed experiments. YHK and KWK wrote the manuscript. NKL and SMS analyzed the data and provided technical support. All authors approved the final version of the paper.*
**Conflicts of interest:** *None declared.*

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